Breakthrough

**A Research Bulletin**
Prepared by Organizational Results
Missouri Department of Transportation

**June 2006**
RI98.006

# New Automated Concrete Evaluation Will Save Time and Money

## Business Issue

Knowledge of the air-void structure in hardened concrete is a valuable tool toward predicting concrete durability and performance. However, current manual methods following ASTM standard C457-90 are extremely time-consuming, tedious and require highly skilled and experienced personnel. Variability of testing results from human subjectivity and other factors also are a concern. Despite these concerns, many DOTs, including MoDOT, continue to depend upon ASTM C457 using a human operator for evaluating the air-void system in hardened concrete. This data is used to make decisions, which may have significant physical and financial impact, both short and long term. An automated system designed to provide reliable ASTM C457 results would save both time and effort while also improving the overall consistency and repeatability of the evaluation process.

## Background

Since 1998, the Missouri Department of Transportation (MoDOT) has collaborated with the National Nuclear Security Administration-Kansas City Plant (NNSA-KCP), a government contractor for the U.S. Department of Energy, to develop a fully automated system capable of reliably analyzing hardened concrete in accordance with ASTM C457 using the linear traverse method. This effort was accomplished in early 2005 resulting in a prototype system specifically designed to analyze a sample of hardened concrete in accordance with ASTM C457's linear traverse method. This system, called ACE for Automated Concrete Evaluation, includes both hardware components for image acquisition and customized software for image analysis and component identification.

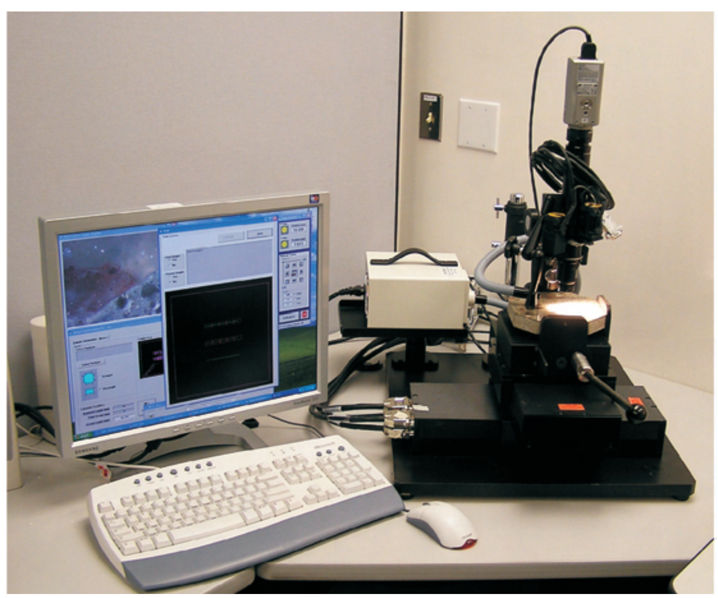

**Figure 1. Prototype ACE system for concrete evaluation.**

The ACE system (shown in Figure 1) uses a high precision, two-dimensional computer-controlled stage to move the concrete sample under a research grade microscope. The image acquisition system consists of a digital color CCD camera, a fire wire digital image acquisition interface, and a 3.2 GHz tower PC. Customized image processing and pattern recognition software has been developed to identify air voids and extract void characteristics. Currently, the system is capable of identifying air voids as small as 5 microns in size. Extracted concrete component characteristics are used to calculate the concrete microscopical properties of interest in accordance with ASTM C457. All system components are linked via a graphical user interface, which aids the operator in the data acquisition, image analysis, and reporting processes (Figure 2).

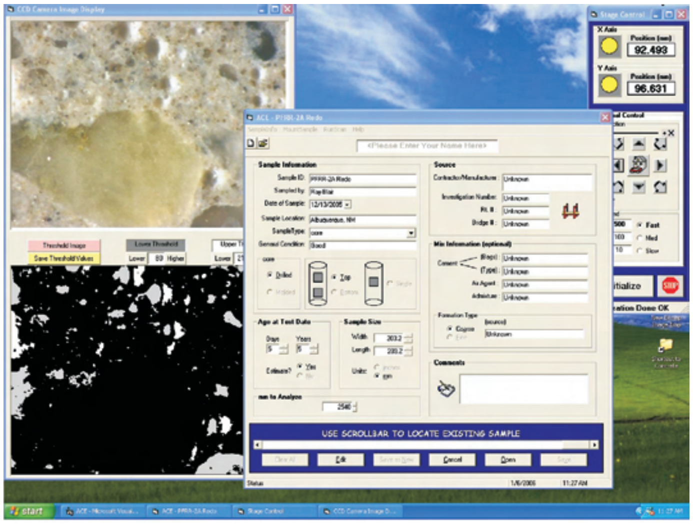

**Figure 2. Graphical user interface for sample scanning and image.**

The ACE system is designed to automatically scan and acquire imagery of a concrete sample. The acquired imagery is then stored on the analysis computer and may be written to a DVD. This latter option allows the acquired imagery to be transferred to another computer for automated analysis. In this way, a single computer workstation may be dedicated to the sample scanning and image acquisition process, while previously acquired imagery can be transferred to and processed on any other available computer.

## Approach

The potential of the prototype system prompted MoDOT in 2002 to take the lead on a national pooled fund effort with several other states to further advance and complete the development of the ACE system with the NNSA-KCP. In addition to funds contributed by Missouri and NNSA-KCP, 12 states have contributed and participated in the pooled fund effort. These states include Arkansas, California, Colorado, Illinois, Indiana, Iowa, Minnesota, Montana, Nebraska, Ohio, Virginia, and Wisconsin. The pooled fund study not only helped secure the project financially, but also provided an opportunity to draw on the experience and knowledge of others with the ASTM C457 test method. In addition, it enabled a much broader range of concrete samples (e.g. various aggregate types, paste characteristics, air-void systems) upon which the ACE system could be improved and validated.

A key component of this pooled fund effort was the execution of a two-phase round robin study[1] among nine laboratories (ten in phase 2) to estimate the variability of the ASTM C457 linear traverse method when applied manually. Sources of known variability associated with the linear traverse include: specimen preparation effects, operator experience and ability, equipment (magnification, method of viewing, lighting), and inherent statistical variability of the method itself. Assessing the variability of the linear traverse test method would then provide a benchmark for performance of the ACE system.

The round robin testing used five concrete specimens that were obtained from different locations around the country. In each phase, the participating labs performed a total of nine linear traverse tests – one linear traverse on four of the specimens, and five linear traverses, using five different sets of traverse lines, on the fifth specimen. All tests were to be run at 100X magnification on the participating lab's equipment. For phase 1, the concrete specimens were prepared by the lab supplying the specimen, using the lab's standard equipment and procedure. For phase 2, the five concrete specimens were collected and the surfaces were prepared again but by one lab. Air void system parameters evaluated for variability in the study included air content, voids per inch, spacing factor, and specific surface.

Findings of the round robin study indicated that wide variations exist in the between-laboratory results derived from the manual application of the ASTM C457-90 standard. This result strongly supports the development of an automated image analysis system for performing ASTM C457 measurements. For the purpose of comparing the round robin results with those derived from the automated ACE results, a smaller subset of the manually derived laboratory results was identified using the results from five of the laboratories that demonstrated the most consistency in their measurements.

### Assessment of ACE Performance Relative to the Round Robin Testing Results

As a way of assessing the performance of the ACE system, the Phase 2 round robin samples, PFRR-1 through PFRR-5, were analyzed by the ACE system. These results were then compared directly to the results derived from manual evaluations of these samples as part of the round robin testing. Further, sample PFRR-2 was analyzed multiple times in order to assess the repeatability of the ACE system. The results are described below.

### Repeatability of the ACE System

To evaluate the repeatability of the ACE system, round robin sample PFRR-2 was analyzed five times, with the sample rotated 90 degrees between analysis runs, generating results for each of the four rotations (Sides A, B, C, and D). For the fifth analysis run, Side A was again ran, but a different set of analysis lines were selected (Side A1).

The analysis results are shown in Table 1 where the mean value of the measured parameters are shown, along with either the standard deviation or the coefficient of variation of each of the parameters across the five analysis runs. Also shown in the table are the repeatability results derived from the round robin testing. As can be seen, the repeatability of the ACE analysis results compare favorably to those derived manually.

### Accuracy of the ACE System

The accuracy of the ACE system is determined through a comparison of the ACE-derived results with those derived manually in the round robin study. Given that the true air-void parameters

[1] Simon, Marcia J., (2005). An Interlab Evaluation of the Variability in the ASTM C 457 Linear Traverse Method. Report. OR6-009, Missouri Department of Transportation, Jefferson City, MO, USA

| ACE Repeatability Test Results --- PFRR-2, Phase 2 | | | | |
|---|---|---|---|---|
| Sample PFRR-2 | % Air | Voids per inch | Spacing Factor | Specific Surface |
| Side A | 5.7 | 17.85 | 0.0036 | 1260 |
| | | | | |
| Side B | 6.035 | 18.82 | 0.00344 | 1247.2 |
| | | | | |
| Side C | 6.165 | 16.6 | 0.00376 | 1076.5 |
| | | | | |
| Side D | 6.41 | 19.32 | 0.0033 | 1207 |
| | | | | |
| Side A1 | 5.74 | 17.8 | 0.0036 | 1238 |
| Mean | 6.01 | 18.08 | 0.0035 | 1205.74 |
| SD | 0.30 | 1.05 | 0.00018 | 74.85 |
| CV (%) | 4.95 | 5.81 | 4.96 | 6.21 |
| Round Robin Repeatability Test Results --- PFRR-2, Phase 2 | | | | |
| Over All Labs | % Air | Voids per inch | Spacing Factor | Specific Surface |
| Pooled SD | 0.35 | | | |
| Pooled CV (%) | | 6.20 | 5.60 | 5.90 |

**Table 1. Repeatability of ACE evaluation process as assessed for PFRR-2.**

for each of the samples is unknown, the 95% confidence interval for each parameter, as computed from the manual round robin results, was used as a comparison metric. In order to succinctly present this comparison data, each of the measured air-void parameters (ACE and round robin) was scaled to the manually derived 95% confidence interval, resulting in a scaled value of between 0.0 (lower limit of the interval) and 1.0 (upper limit of the interval). Hence, a scaled value of 0.50 means the particular air void parameter fell in the center of the 95% confidence interval (i.e., at the mean measured for the parameter). Any value less than 0.0, or greater than 1.0, would be considered to fall outside the 95% confidence interval.

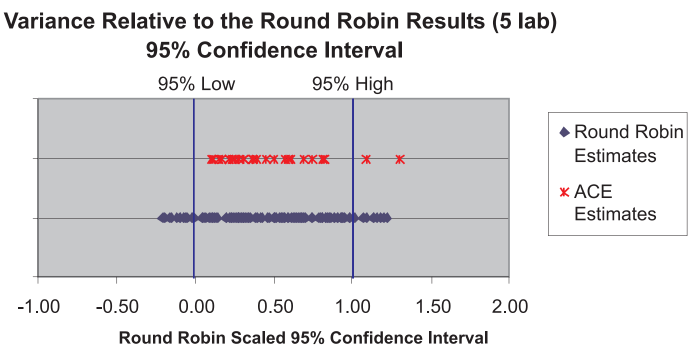


**Figure 3.**

This comparison is shown in Figure 3 where the ranges of the ACE derived and manually derived air-void parameters (25 per each data source) are shown relative to the 95% confidence interval. As can be seen from the figure, the manually derived results from the round robin testing do display some variability across the samples. The ACE derived results also demonstrate a similar variability, but compare favorably with the manually derived results.

### *Overall Agreement*

The ultimate goal of any manual or automated process that implements ASTM C457-90 is to assess the overall quality of the measured sample, and to determine if the sample meets standards or does not. Overall agreement between the ACE system and manual operators is established if the overall "accept vs. reject" decision provided by the ACE agrees with the decision provided by a manual operator. For comparison purposes, the spacing factor and specific surface parameters were used to compare automated decision to manual decisions. Industry accepted limits for these two parameters are that the spacing factor for a sample be less than .008 in. and the specific surface be greater than 600 in.$^{-1}$ Figures 4 and 5 show comparisons of the ACE-derived values and the manually-derived values for these two parameters. These figures show that, at least for the five round robin samples analyzed in this study, the ACE system provides measurements of theses two parameters, which are in agreement with the manually derived results. Further, these figures also show that ACE, again for at least the five round robin samples used in this study, never rejects a sample that manual results indicate should be accepted (Type I testing error), nor does the ACE accept samples that manual results indicate should be rejected (Type II testing error). As such, the automated system provides "accept vs. reject" decisions which are identical to those provided by manual analysis.

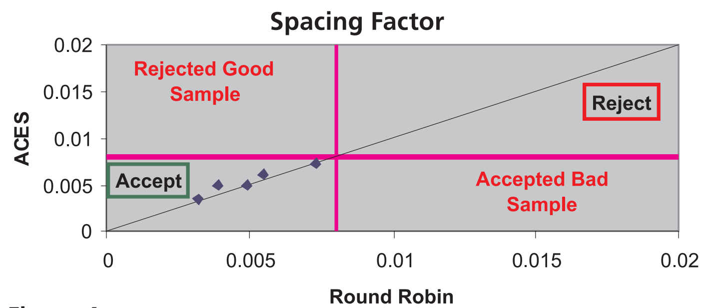


**Figure 4.**

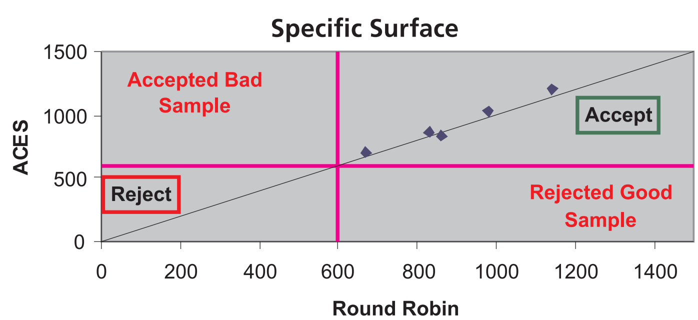


**Figure 5.**

## Findings and Conclusions

The results of this study provide a number of findings and conclusions as detailed below:

- Given the variability, which is recognized to exist in manually derived ASTM C457 linear traverse results, the ACE-derived results fall reasonably well within this variability and are comparable to the round robin manually derived ASTM C457 results.

- The ACE image acquisition and analysis process requires 7-8 hours of computer time, but only 10 – 20 minutes for the operator to mount the sample and set all scan parameters. As such, a major savings in labor time is realized through the use of the ACE system.

- While the ACE scanning and image acquisition processes require a dedicated computer, the analysis of the archived imagery can be performed on any computer.
- Results of this study indicate that the repeatability, accuracy, and overall assessment quality of the ACE system in conducting the ASTM C457 linear traverse method are comparable to results obtained by manually (human-based) conducting ASTM C457 linear traverse method.

## For More Information


Patty Lemongelli, P.E.
Missouri Department of Transportation
(573) 526-4328
*patricia.lemongelli@modot.mo.gov*

Chris Baumgart, Ph.D.
National Nuclear Security Administration / Kansas City Plant
(505) 844-2585
*cbaumgart@nnsa.doe.gov*